Project Number:	705
Category:	*Floating Offshore Wind Turbines*
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Subject:	*Design Guidelines for Station Keeping Systems of Floating Wind Turbines*
Performing Activity:	American Bureau of Shipping (ABS)
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Contracting Agency:	Bureau of Safety and Environmental Enforcement
Summary:	The following four major tasks were accomplished in this project: • Conducting a state-of-the-art review of the technologies relevant to the design of FOWT stationkeeping systems; • Performing case studies to explore the global response characteristics of typical FOWT conceptual designs with a particular focus on the sensitivity of FOWT global responses to various design and analysis parameters; • Identifying important design parameters and technical challenges for the design of FOWT stationkeeping systems; and • Proposing a design guideline to provide recommended practices for FOWT stationkeeping systems.
Key Findings:	Based on the results of global performance analyses for the load cases presented for the SPAR FOWT in Oregon, the following conclusions were made: • Turbine components loads (e.g. blade root bending and shaft bending moments) are governed by DLC 1.3 (power production) in combination with the extreme turbulent wind model. • Tower base loads and mooring loads are governed by DLCs 6.1 and 6.2 with the parked turbine. • Collinear winds and waves, in general, result in larger maximum mooring loads and larger platform offsets. • A misalignment of wind and wave may result in a smaller minimum line tension. • A misalignment of wind and wave may result in a larger maximum platform yaw motion. • A misalignment of wind and wave may result in larger maximum tower base loads. However, the effects appear to be marginal. • Platform yaw motions are more sensitive to the effects of yaw errors and blade faults (blade fault in DLC 7.1, and yaw error in DLC 6.2, DLC 7.1, and the survival load cases) with comparison to the hull global motions of other degrees of freedom and line tensions. • Yaw error and blade fault conditions (blade fault in DLC 7.1, and

nacelle yaw error in DLC 6.2, DLC 7.1, and the survival load cases) are more critical for the design of wind turbine components than the SPAR hull structure and the stationkeeping system.
- Ratios of the SPAR FOWT responses to the 500-year return site conditions to the 50-year return site conditions show that the ratios of the maximum line tension range between 1.17 and 1.18; the ratios of the maximum tower base loads range between 1.23 and 1.24.

Based on the results of global performance analyses for the load cases presented to the semisubmersible FOWT in the Gulf of Mexico (GOM) (i.e., the GOM Central Region, as defined in API 2INT MET, 2007), Maine, and Oregon, the following conclusions were made:

- Yaw error and fault conditions (blade pitch runaway and nacelle yaw runaway in DLC 2.1; blade fault in DLC 7.1; and nacelle yaw error in DLC 6.2, DLC 7.1, and the survival load cases) are critical for the design of wind turbine components. However, fault conditions are generally not critical for the design of the semisubmersible support structure and the stationkeeping system.
- For normal conditions without occurrence of faults (DLC 1.x, DLC 3.x, DLC 4.2, DLC 5.1, DLC 6.1, and DLC 6.3), turbine components loads (e.g. blade root bending and shaft bending moments) are generally governed by DLC 1.3 (power production) in combination with the extreme turbulent wind model in Maine and Oregon.
- Turbine blade loads (blade root bending and shaft bending moments) are governed by DLC 6.1 and the survival load cases with the parked turbine in GOM.
- Hull motions and mooring loads are generally governed by DLCs 6.1 and 6.2 and the survival load cases with the parked turbine for all the three sites.
- Tower base loads are governed by DLCs 6.1 and 6.2 and survival load cases with the parked turbine in GOM, as well as DLC 1.3 with the operating turbine in Maine and Oregon.
- DLCs 1.4, 1.5, 3.x, 4.x, and 5.x with transient effects may result in larger maximum responses than DLC 1.3. However, the effects appear to be marginal.
- Collinear wind and wave conditions generally result in larger maximum mooring loads and larger platform offsets.
- A misalignment of winds and waves may result in larger maximum platform yaw motion and larger maximum tower base loads. However, the effects appear to be marginal.
- For the semisubmersible FOWT with the parked turbine, the ratios of a 500-year return to 50-year return global responses are:
    - Maximum line tension: 1.40 to 1.42 (GOM); 1.33 to 1.34

	(OR); and 1.14 to 1.15 (ME); and o Tower base load: 1.71 to 1.77 (GOM); 1.33 to 1.34 (OR); and 1.23 to 1.25 (ME). Based on the results of global performance analyses for the load cases presented for the Tension Leg Platforms (TLP) FOWT in GOM and Oregon, the following conclusions were made: • Yaw error and fault conditions (blade pitch runaway and nacelle yaw runaway in DLC 2.1; blade fault in DLC 7.1; and nacelle yaw error in DLC 6.2, DLC 7.1, and the survival load cases) are more critical for the design of wind turbine components than for the design of the TLP support structure and the stationkeeping (tendon) system. • Platform yaw motions are more sensitive to the effects of yaw error and blade faults (blade pitch runaway and nacelle yaw runaway in DLC 2.1; blade fault in DLC 7.1; and nacelle yaw error in DLC 6.2, DLC 7.1, and the survival load cases) compared to other degrees of freedom of hull global motions and tendon tensions. • For normal conditions without occurrence of faults (DLC 1.x, DLC 3.x, DLC 4.2, DLC 5.1, DLC 6.1, and DLC 6.3), turbine components loads (e.g. blade root bending and shaft bending moments) are generally governed by DLC 1.3 (power production) in combination with the extreme turbulent wind model in Oregon. • Turbine blade loads (e.g. blade root bending) are governed by DLC 6.1 and the survival load cases with the parked turbine in GOM. • Hull motions and tendon loads are generally governed by DLCs 6.1 and 6.2 and the survival load cases with the parked turbine for both the Oregon and GOM sites. • Tower base loads are governed by DLCs 6.1 and 6.2 and the survival load cases with the parked turbine for both the Oregon and GOM sites. • DLCs 1.4, 1.5, 3.x, 4.x, and 5.x with transient effects may result in higher maximum responses than DLC 1.3. However, the effects appear to be marginal. • Collinear wind and wave in general result in larger maximum tendon tensions and larger maximum platform offsets. • Misalignment of wind and wave may result in smaller minimum tendon tensions. • Misalignment of wind and wave may result in larger maximum tower base loads. However, the effects appear to be marginal. • For the TLP FOWT with the parked turbine, the ratios of 500-year return to 50-year return global responses are: o Maximum line tension: 1.15 to 1.17 (GOM) and 1.16

	(OR); and ◦ Tower base loads: 1.42 to 1.51 (GOM) and 1.31 to 1.32 (OR). Based on the results of global performance analyses for the three platforms considered, it can be concluded that: • Turbine component (e.g. blade, drive train and yaw bearing) loads of the semisubmersible and TLP FOWTs are close to those of the land-based wind turbine. • Tower base loads of the semisubmersible FOWT are higher than those of the land-based turbine. • Tower base loads of the TLP FOWT are close to those of the land-based turbine.
Recommendations:	• More research is needed in the following areas: ◦ Validation of global performance analysis tools; ◦ FOWT model testing method; and ◦ FOWT design load cases. • Design guidelines should be drafted for stationkeeping systems of FOWT's. Continued refinement and consensus building is needed to turn this into an accepted design guide.
Subsequent Studies/Activities:	• FY 2014 study award *Fatigue Design Methodologies Applicable to Complex Fixed and Floating Offshore Wind Turbines*
Report Link:	AA: Qing Yu, Xiaohong Chen, Design Guideline for Stationkeeping Systems of Floating Offshore Wind Turbines, Final Report. June 2013.
	AB: Project Close-out meeting Presentation